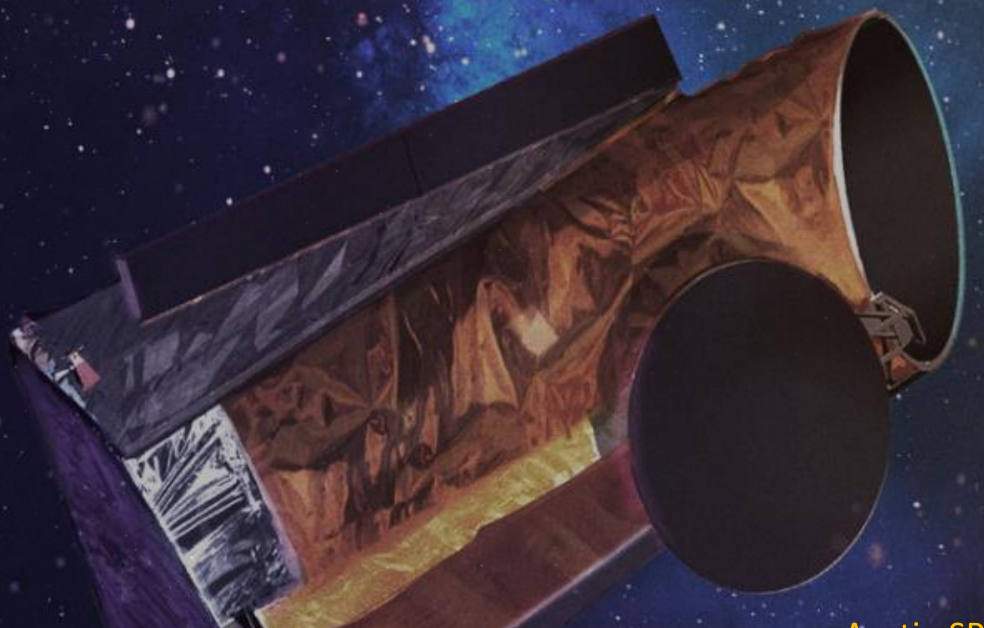
The Habitable Exoplanet Observatory Mission Concept

Exploring Nearby Planetary Systems and Enabling a Broad Range of General Astrophysics & Solar System Science in the UV through the near-IR



Bertrand Mennesson

Study Scientist, Jet Propulsion Laboratory, California Institute of Technology

and the HabEx Study Team

Outline

- HabEx Study charter, philosophy & science goals
- HabEx Architecture A: design concept and expected performance
- Lessons learned
- Path forward

Study charter

- NASA chartered 4 potential flagship mission concept studies in 2016 to support the 2020 US Decadal Survey
- Concept studies intended to describe missions scientific rationales and design, including cost estimates
- The Habitable Exoplanet Imaging Mission **(HabEx)** community-wide Science and Technology Definition Team (STDT) was appointed by NASA in March 2016, with JPL as lead NASA Center
- Interim reports were submitted for all four studies in March 2018 and will be posted this summer at *https://www.jpl.nasa.gov/habex/*
- Final Study Report due to NASA and National Academies in June 2019*

HabEx STDT

HabEx STDT Meeting, May 16-17 2016, Washington, DC. Team members from left to right: Rachel Somerville, David Mouillet, Shawn Domagal-Goldman, Leslie Rogers, Martin Still, Olivier Guyon, Paul Scowen, Kerri Cahoy, Daniel Stern, Scott Gaudi, Bertrand Mennesson, Lee Feinberg, Karl Stapelfeldt, Sara Seager, Dimitri Mawet. Missing STDT members (unable to attend meeting in person): Jeremy Kasdin, Tyler Robinson and Margaret Turnbull.

19 STDT Members

6 International Observers (ESA, JAXA, DLR, CNES, CSA, SRON)

HabEx

Study Philosophy

"Develop an optimal* mission concept for characterizing our nearest planetary systems, and detecting and characterizing a handful of ExoEarths."

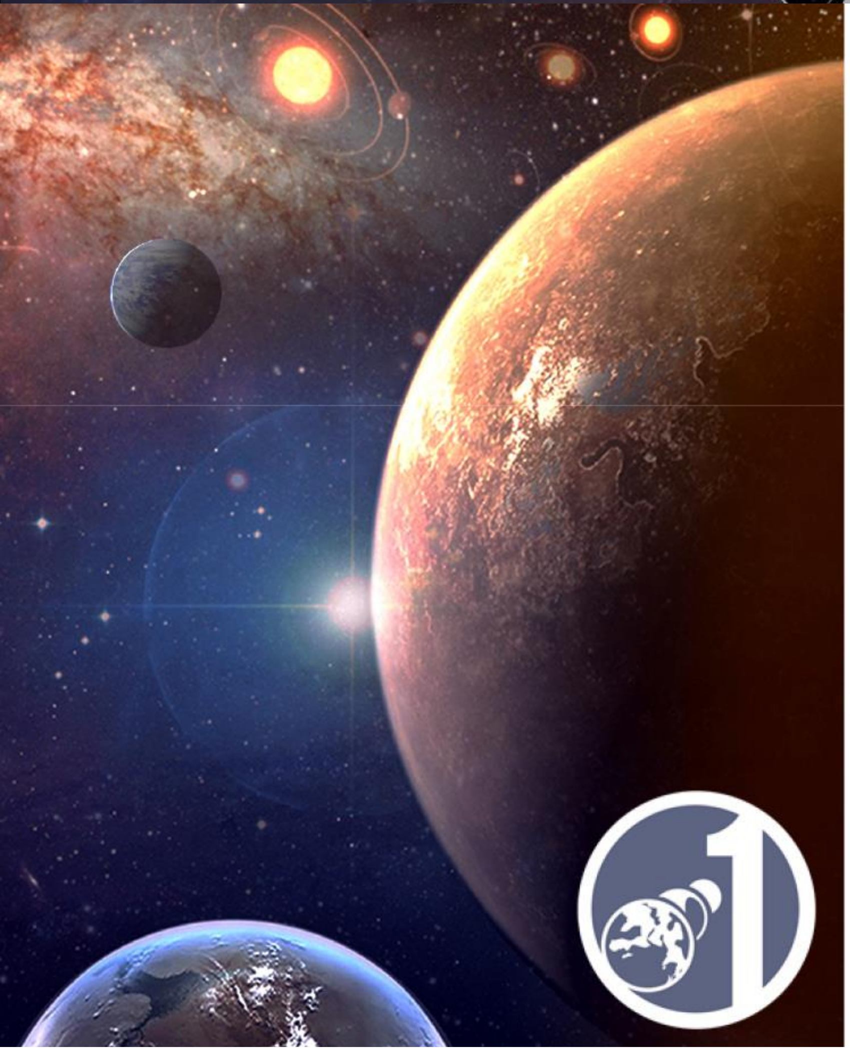
"Given this optimal* concept, maximize the general astrophysics science potential without sacrificing the primary exoplanet science goals."

What does optimal mean?

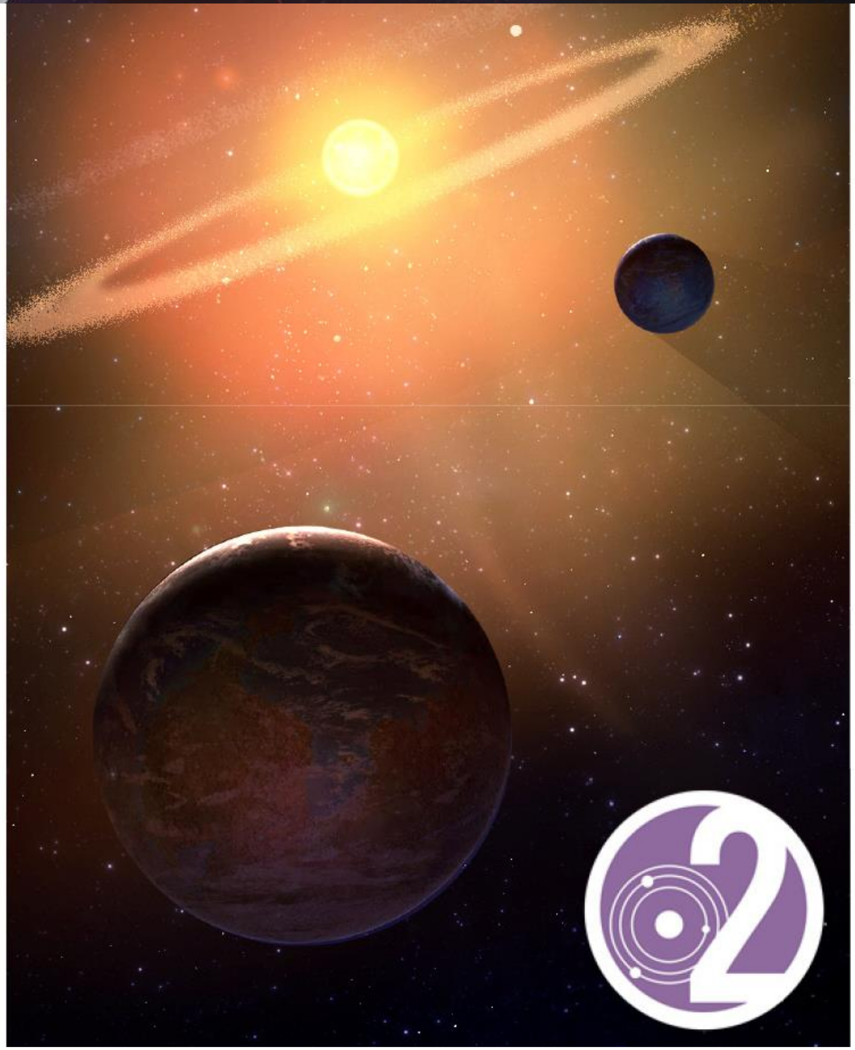
- Maximizing the science yield while maintaining feasibility, i.e., adhering to expected constraints.
- Constraints include: Cost, technology (risk), time to develop mission.

HabEx

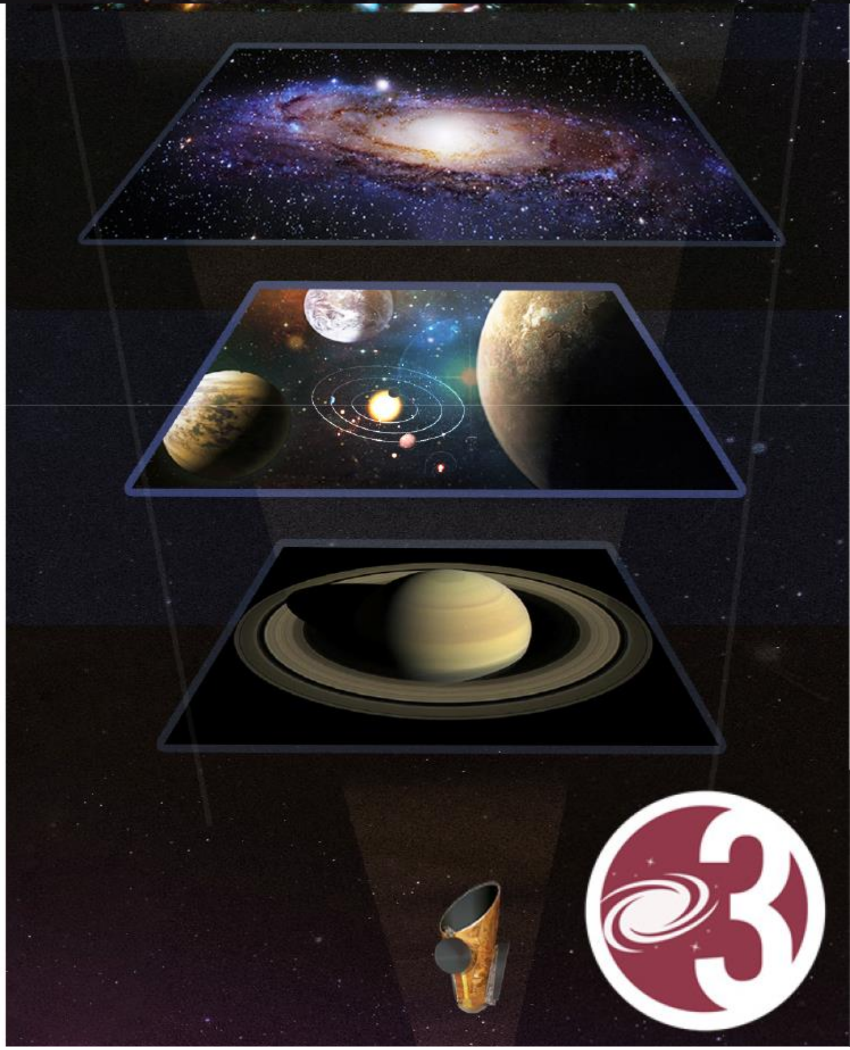
Science Goals



Seek out nearby worlds and explore their habitability



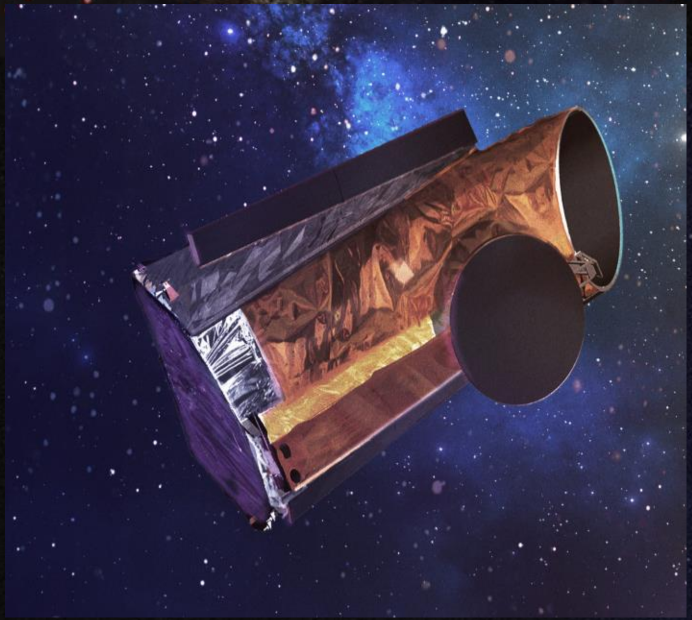
Map out nearby planetary systems and understand their diversity.

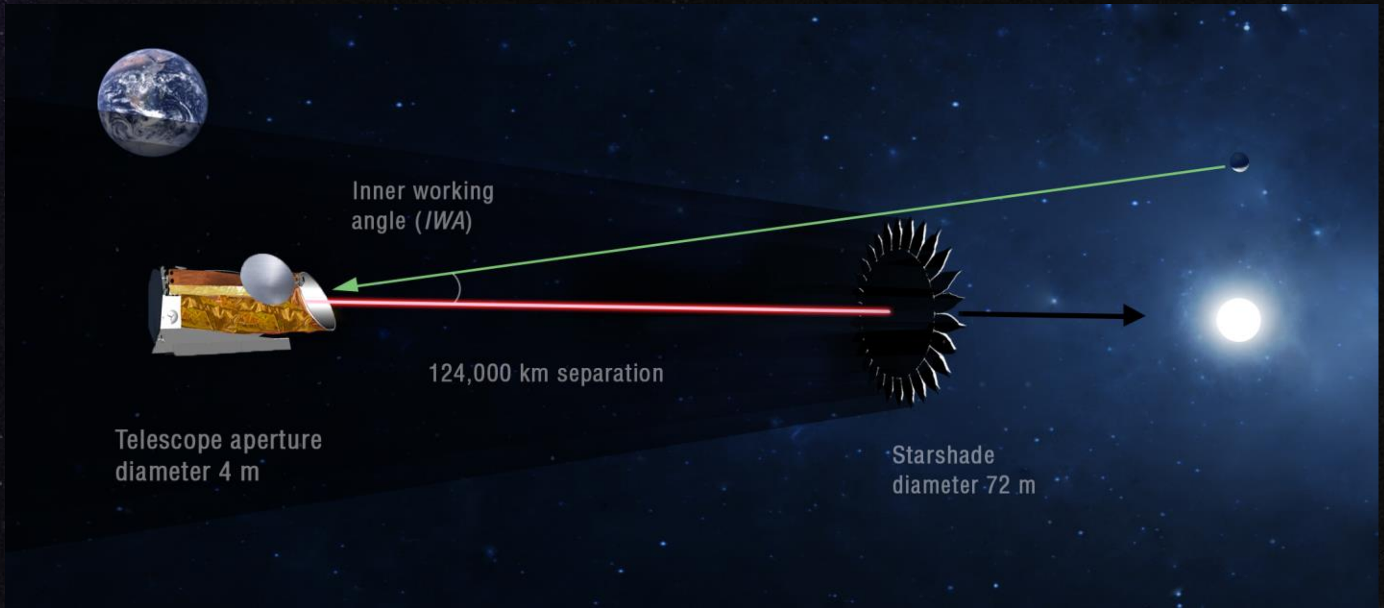


Open up new windows in the Universe from the UV to NIR.

Architecture A at a glance

	Habitable Exoplanet Imaging Mission
Mission Duration	5 years (10 years consumables)
Orbit	Earth-Sun L2 Halo
Telescope Aperture	4-meter unobscured
Telescope Type	Off-axis three-mirror anastigmat
Primary Mirror	4-meter monolith; glass-ceramic substrate; Al+MgF2 coating
Instruments (4)	Exoplanet science: Coronagraph, Starshade Observatory science: UV Spectrograph, Workhorse Camera
Attitude Control	Slewing: hydrazine thrusters; Pointing: microthrusters



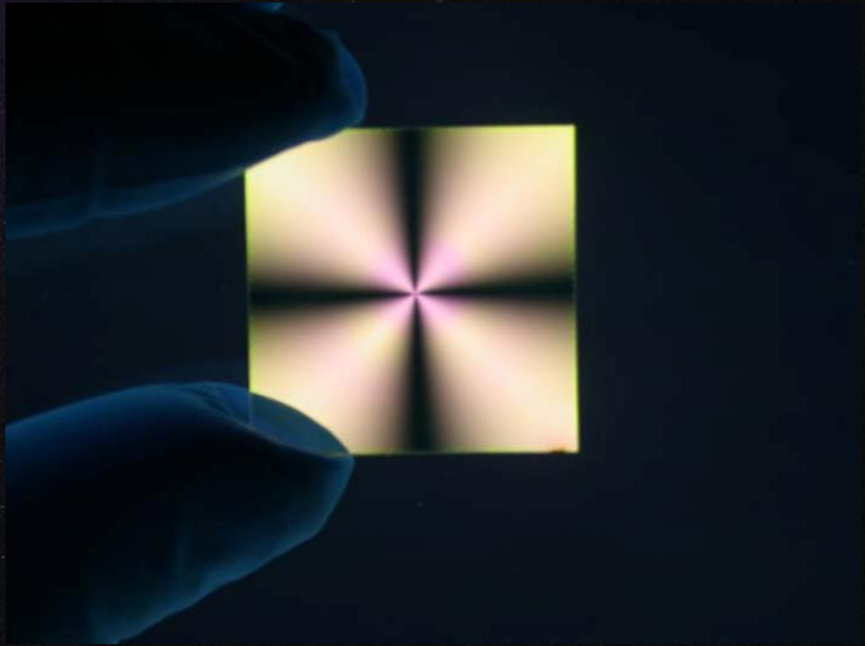


- **Off-axis f/2.5 monolithic primary**
- **Coronagraph Instrument (0.45 - 1.8 μm)**
    - **R=140 in the visible, R=40 in the NIR**
    - **IWA = 62 mas at 0.5 μm**
- **Starshade Instrument (0.2 – 1.8 μm)**
    - **R=140 in the visible, R=40 in NIR, R=7 in UV**
    - **IWA = 60 mas over 0.3 to 1.0 μm**
    - **Slew to different distances to cover <0.3 or >1μm**

Hybrid Design and Observing Strategy *(see Chris Stark's talk)*

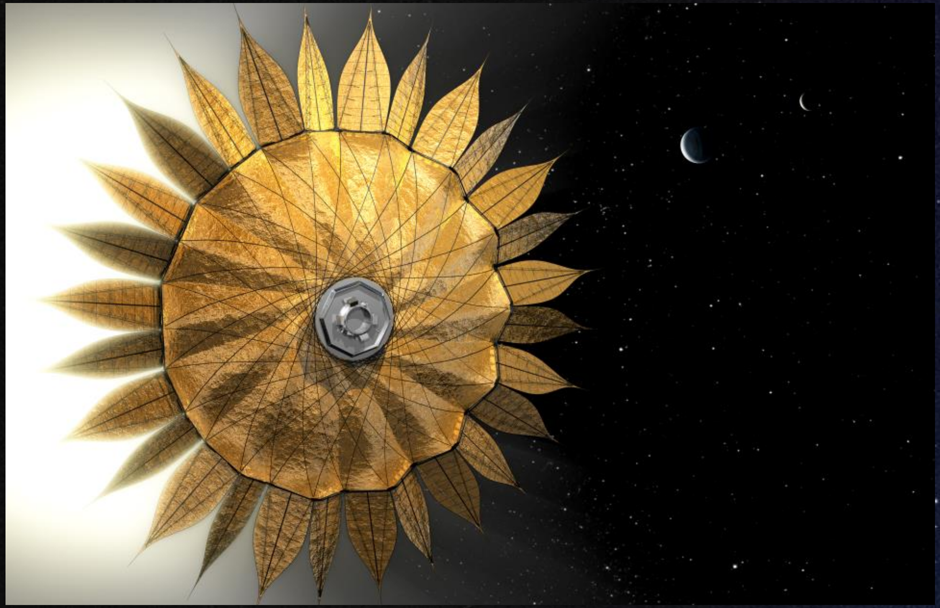
Architecture A combines the strengths of two highly complementary starlight suppression systems:

Internal CORONAGRAPH



+

External STARSHADE



- Very nimble
- Searches for planets around many stars
- Takes images at multiple visits to measure orbits

- Very "photon" efficient
- Accesses closer-in planets at a given λ
- Takes broad spectra of all planets found in ~50-100 most interesting systems

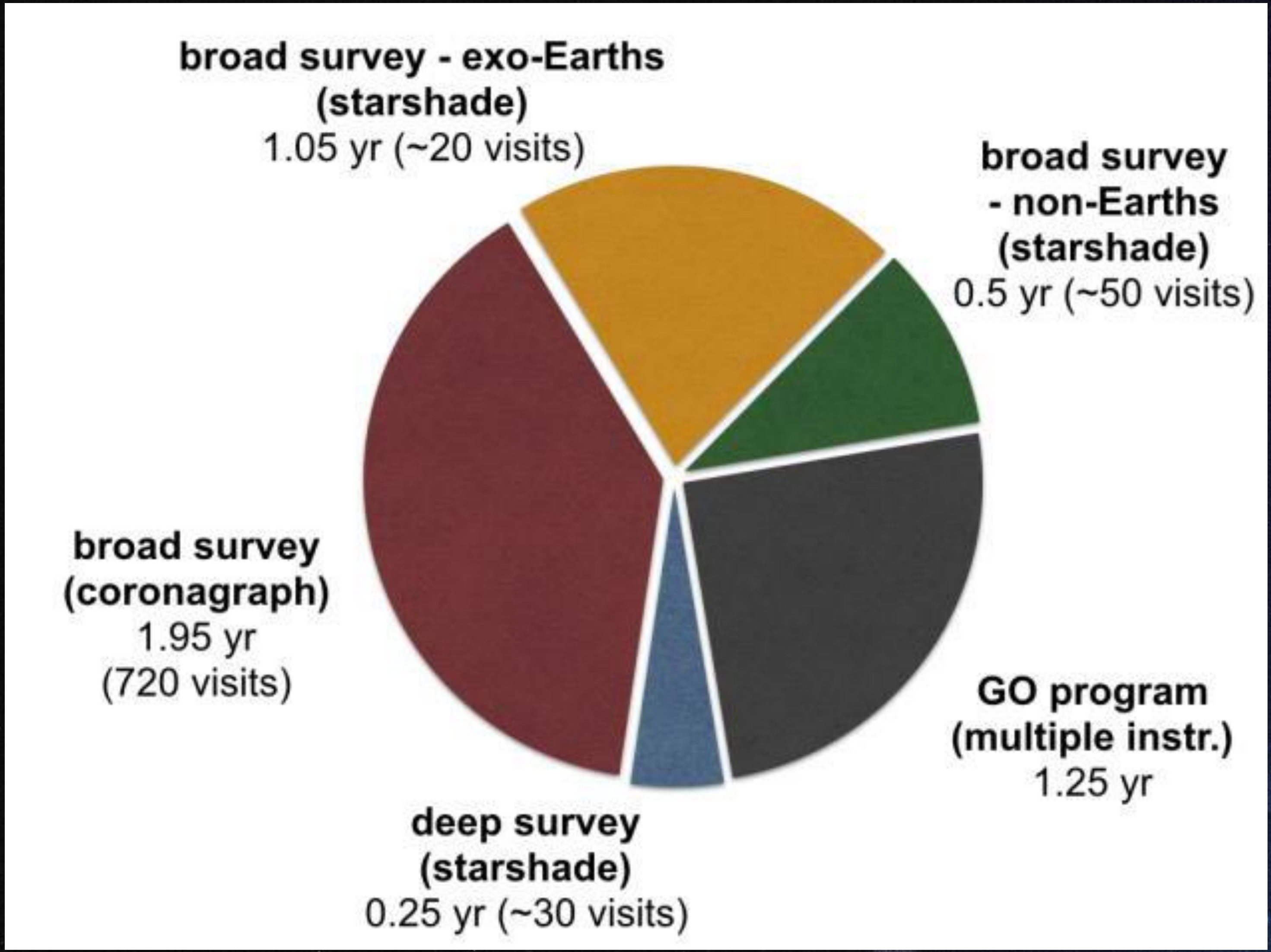
HabEx Exoplanet Survey Strategy

Broad Survey (3.5 year total)

- Roughly 110 stars
- Roughly 6 observations of each
- 50% completeness for exo-Earths
- Spectra of most interesting systems (and all those with EECs)
  - 0.3-1.0 μm at once with starshade
  - R=7 (grism) 0.3-0.45 μm
  - R=140 (IFS) 0.45-1.0 μm

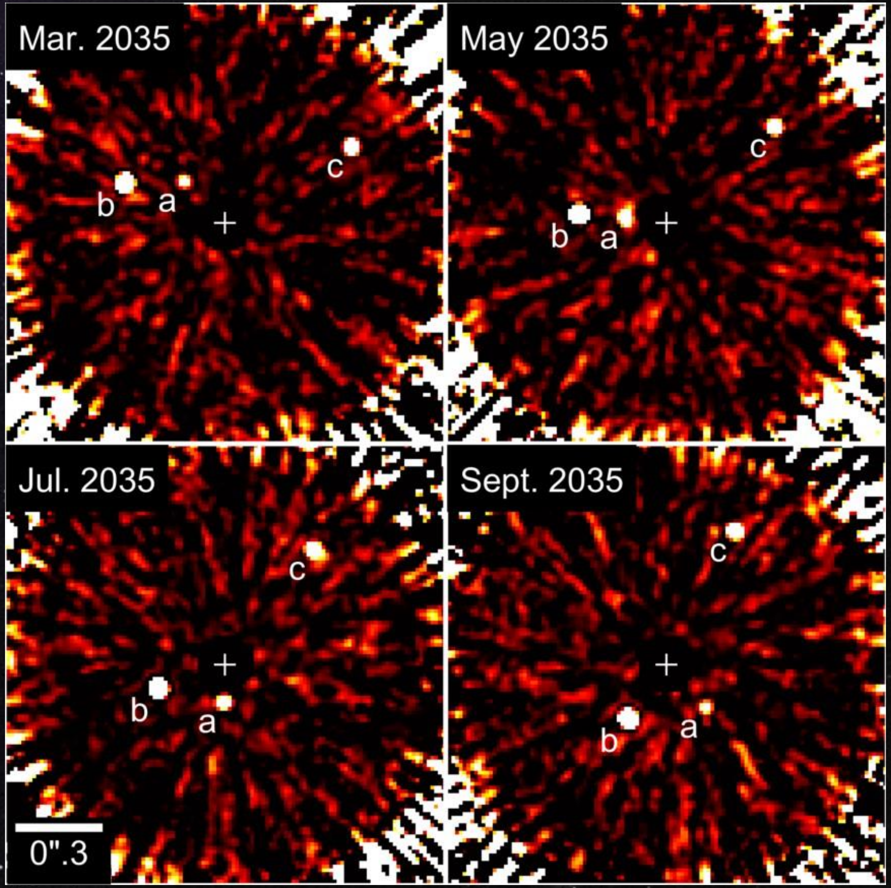
Deep Survey (0.25 year)

- Roughly 10 high-priority close-by (<6pc) GK dwarfs
- Deep broadband image to the systematic floor
- Spectra



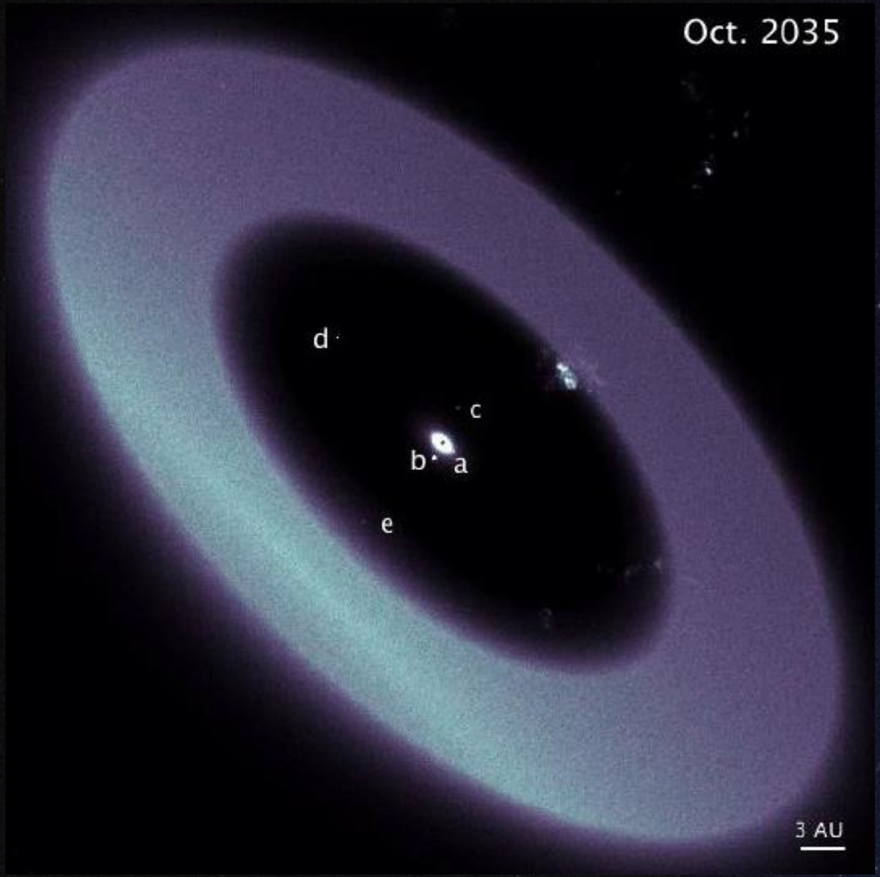
Detecting and Characterizing Potentially Habitable Worlds

- HabEx will survey ~110 nearby sunlike stars with the coronagraph to search for potentially habitable worlds and determine their orbits



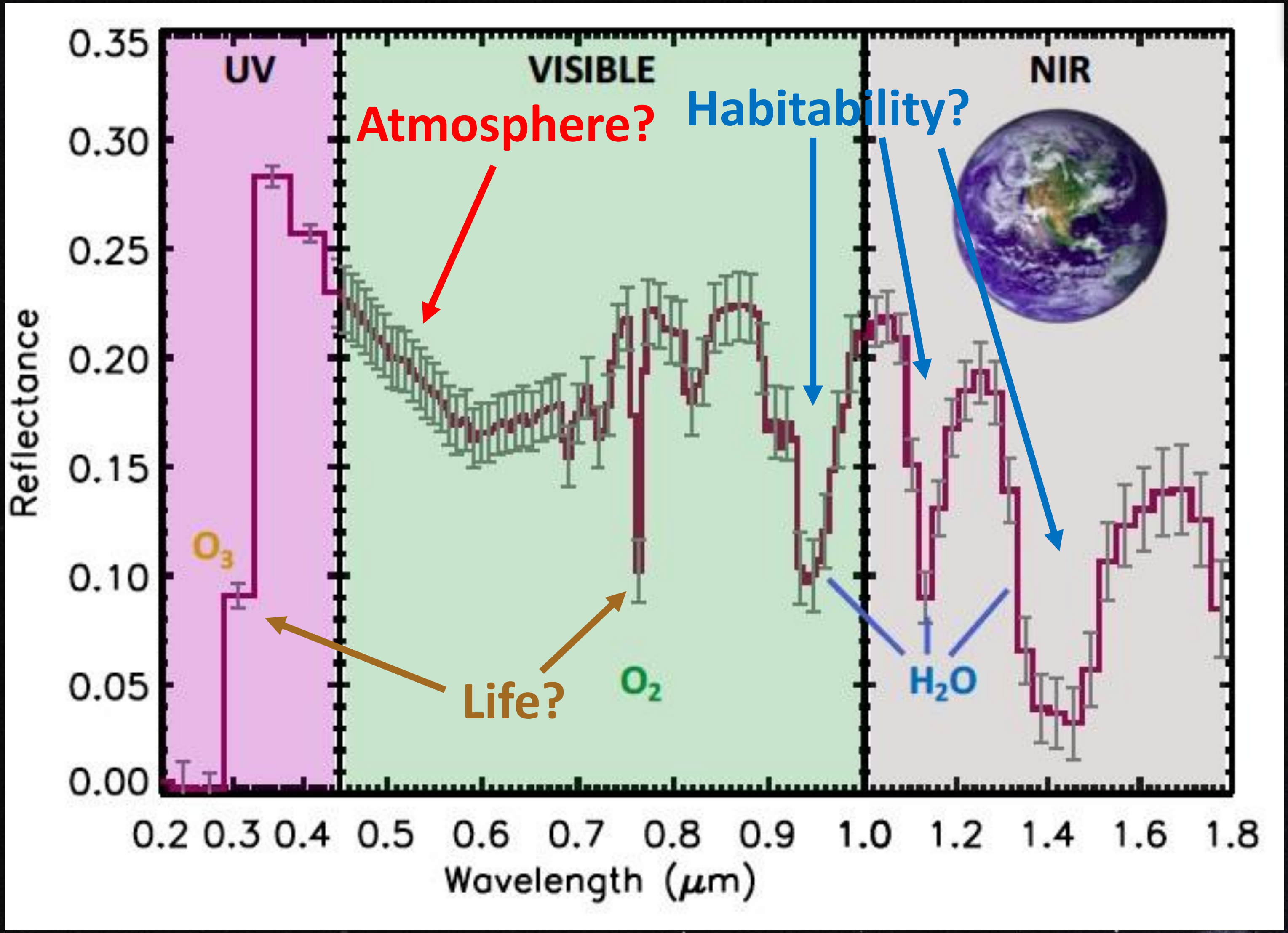
Credit: Garreth Ruane (Caltech)

- Most interesting systems will be studied further with the starshade (broad-band 12” x 12” image and spectra of individual planets)



Credit: Sergi Hildebrandt (JPL)

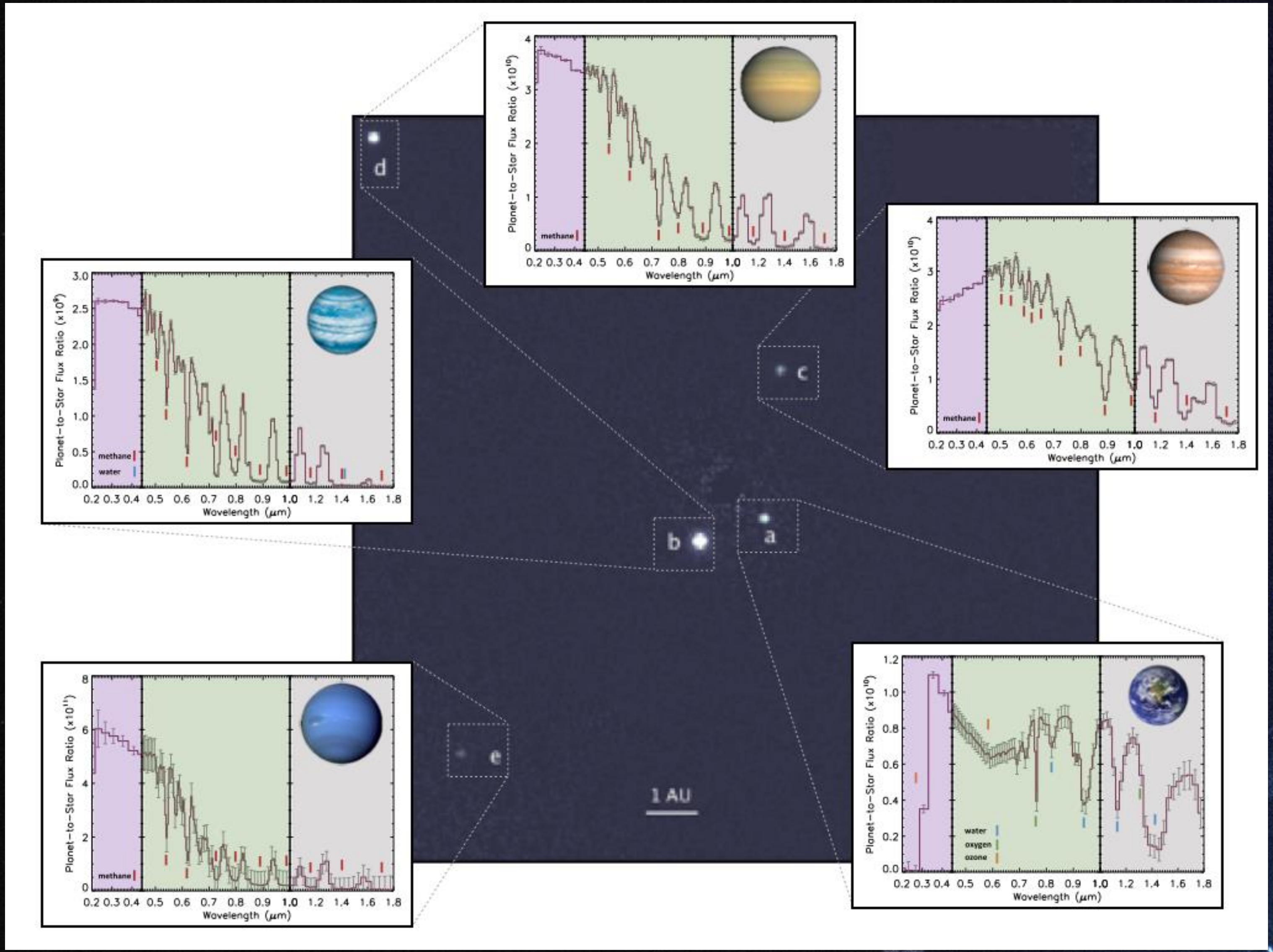
Exo-Earth near UV to near IR Spectra



Credit: Tyler Robinson

Family Portraits of our Neighboring Planetary Systems

- Spectra over 0.3-1.0 μm at once with starshade for planets within 1.5”
  - R=7 (grism) 0.3-0.45 μm
  - R=140 (IFS) 0.45-1.0 μm
- Near UV and/or near UV spectra for select systems



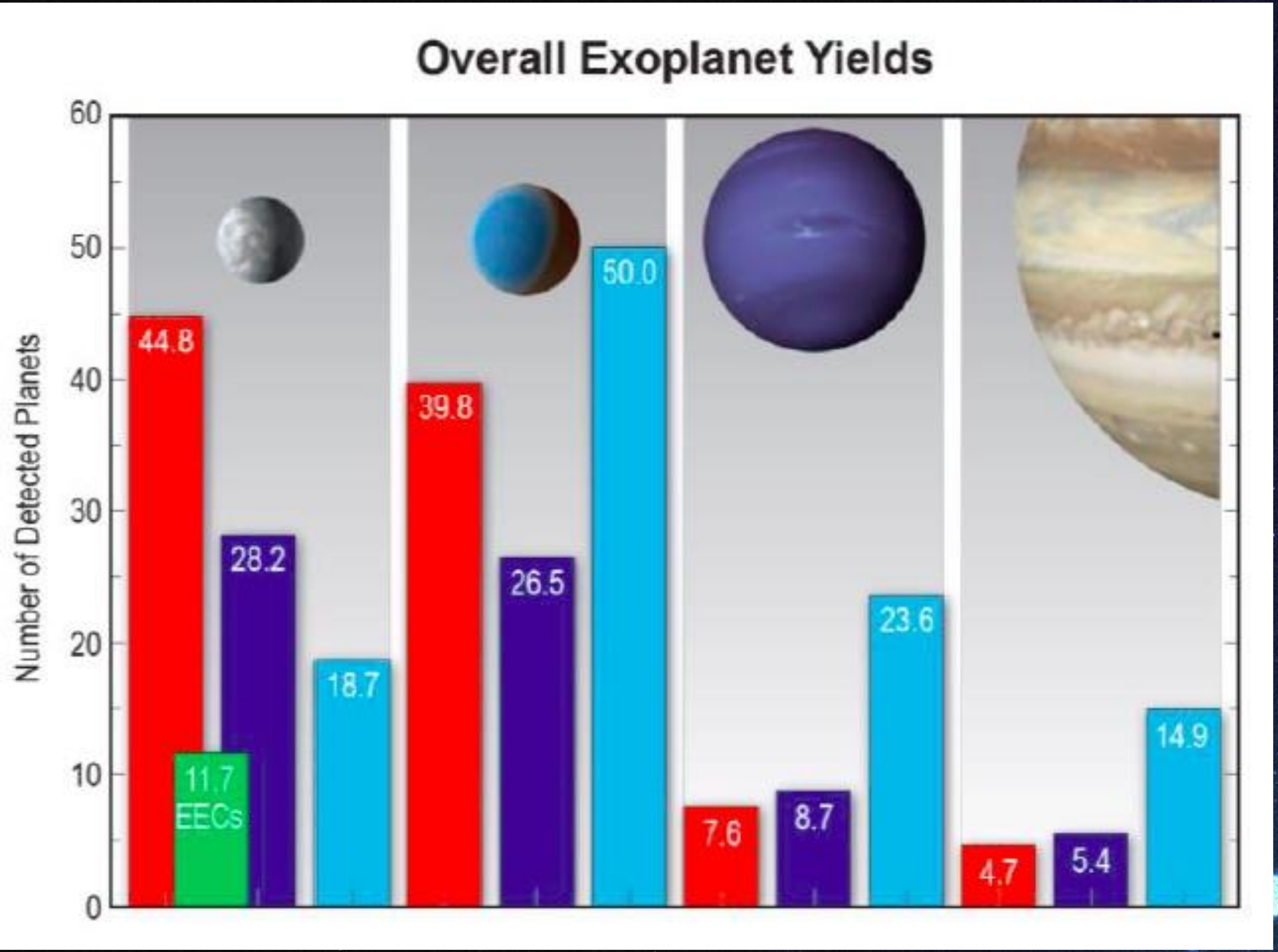
Credit: Tyler Robinson (NAU) & Sergi Hildebrandt (JPL)

Yields of Characterized Planets *(Chris Stark, STScI)*

Expected HabEx Yields*

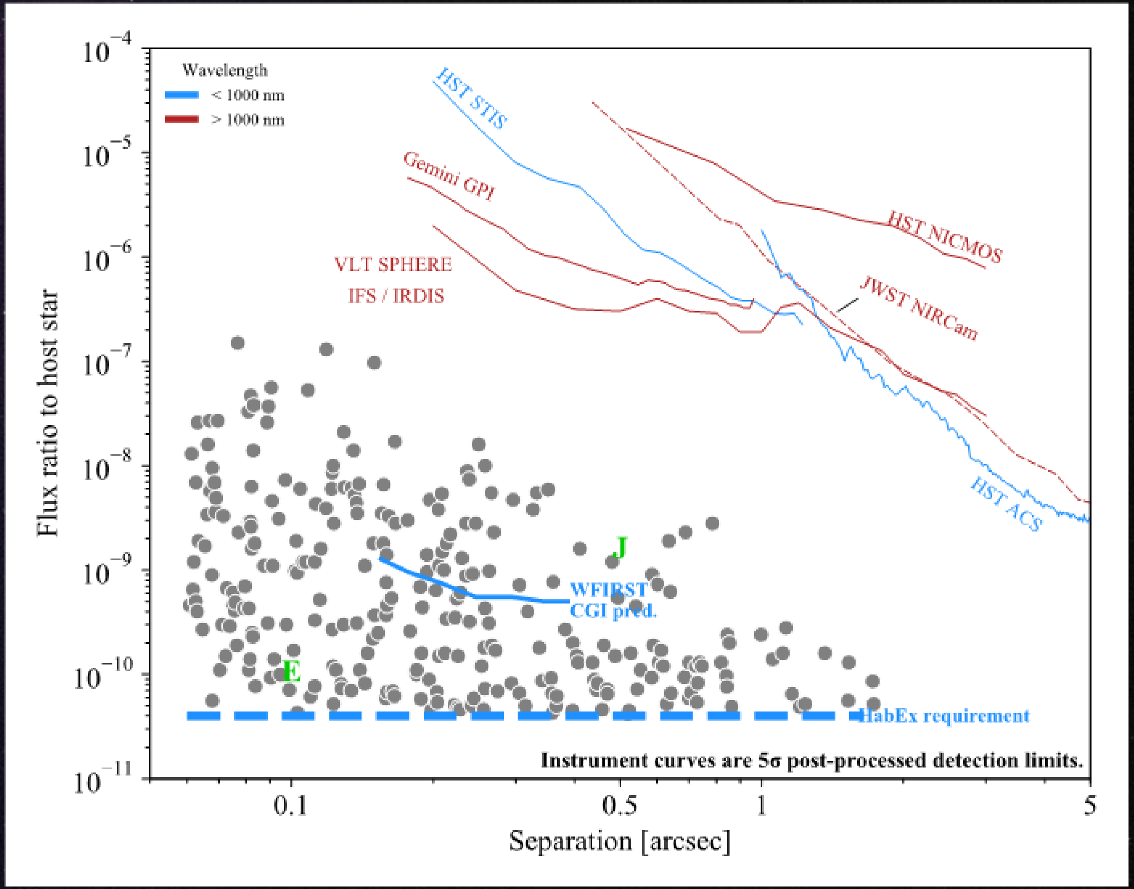
Detect and characterize the orbits and atmospheres of:

- Rocky planets:
  - 92 rocky planets (0.5-1.75 R_E)
  - Includes 12 Earth Analogs (0.6-1.4 R_E)
- Sub Neptunes:
  - 116 sub-Neptunes (1.75-3.5 R_E)
- Gas Giants
  - 62 gas giants (3.5-14.3 R_E)



*Assumes SAG13 Nominal Occurrence Rates.

Overall Planet Yields for 5-year primary mission*



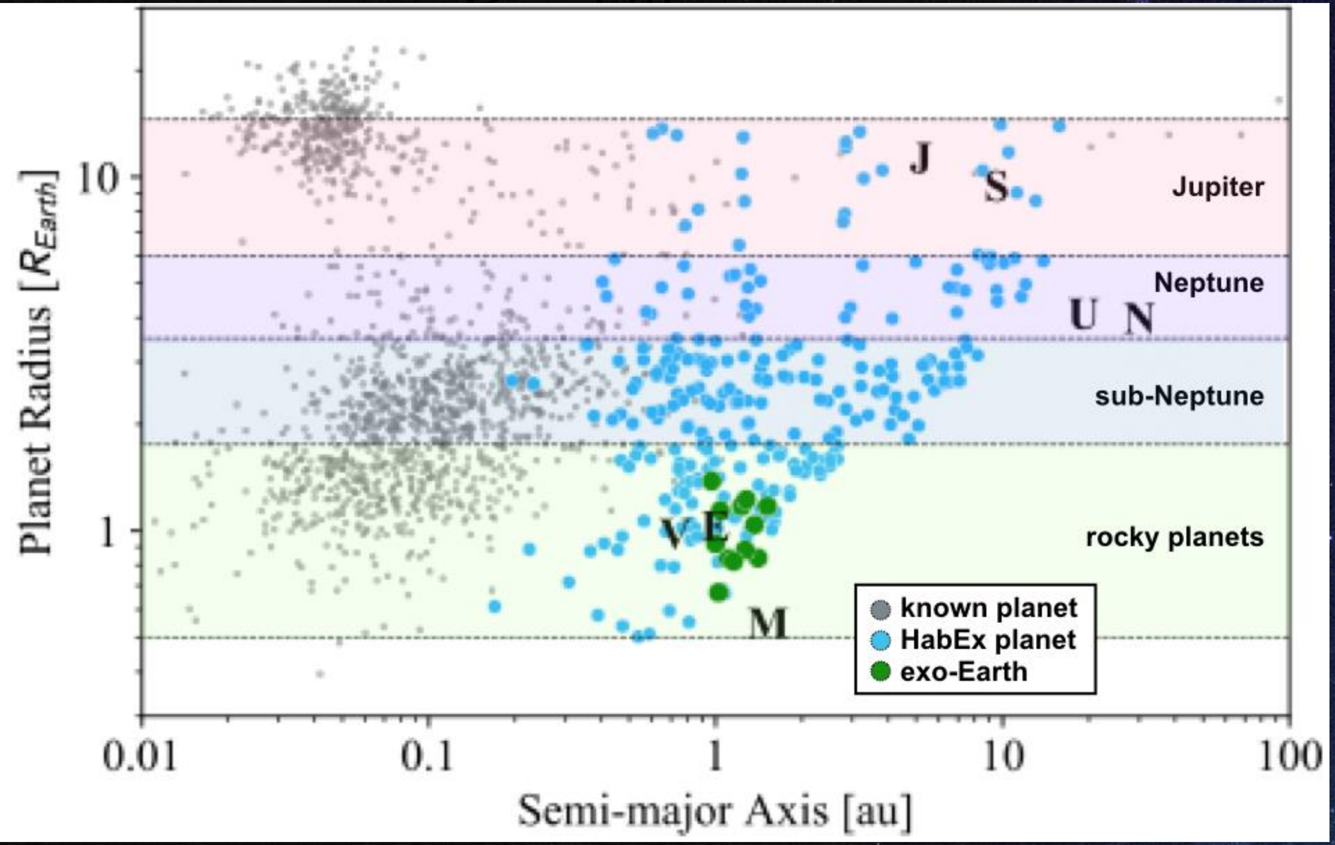
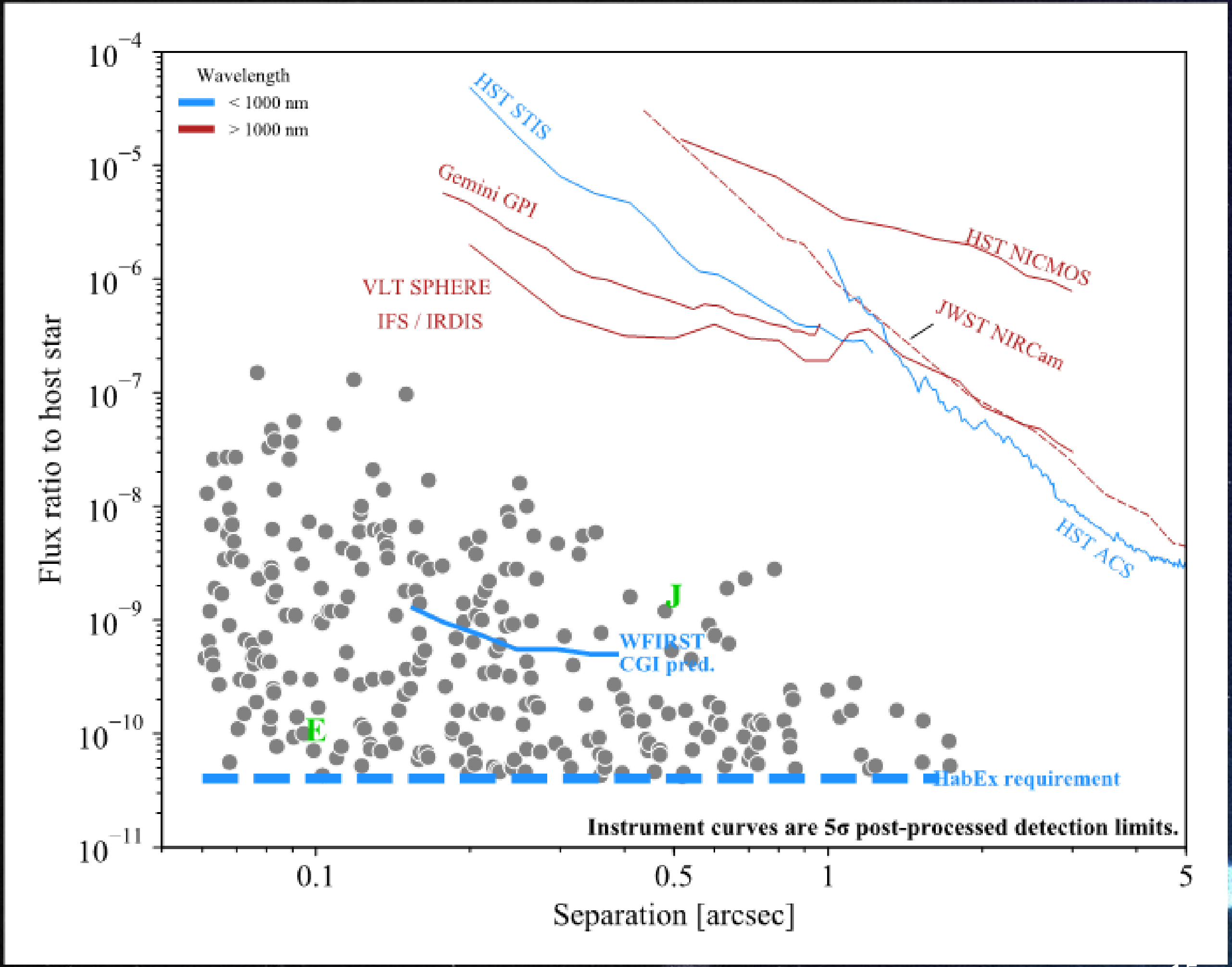


Figure Credit: Tiffany Meshkat (IPAC) & Dan Stern (JPL)

(*): estimated using SAG 13 nominal occurrence rates ; all HZ EECS have orbits determined and 0.3 – 1.0 μm spectra ; over 50% of all planetary systems found will have 0.3 – 1.0 μm spectra taken

Capabilities: Direct Imaging

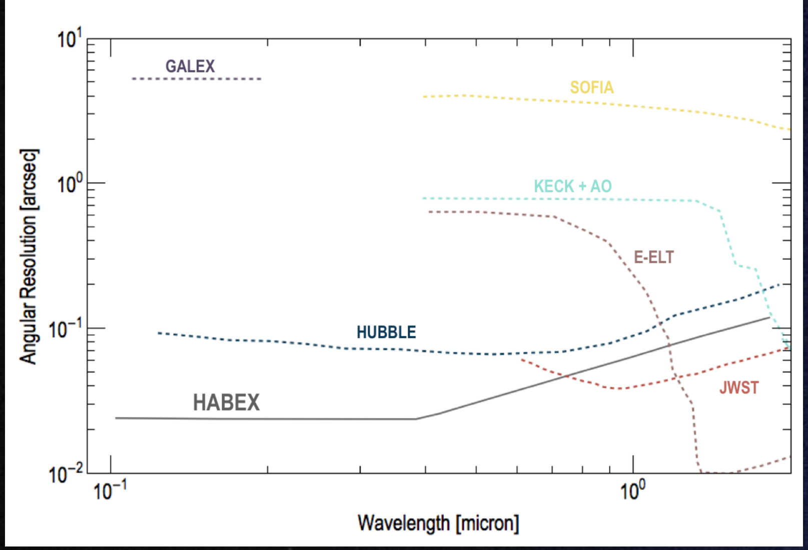
- Minimum contrast: 4×10^{-11}
- Inner Working Angles:
  - 0.06” at 0.3-1 µm (starshade, λ dependent)
  - 0.062” at V band (coronagraph)
- Outer Working Angles:
  - 6” (imaging, starshade)
  - 1.5” (spectra, starshade)
  - 1” (imaging, coronagraph)
- Spectroscopy
  - R=7 from 200 to 450 nm (starshade)
  - R=140 from 450 to 1000 nm
  - R=40 from 1 to 1.8 µm

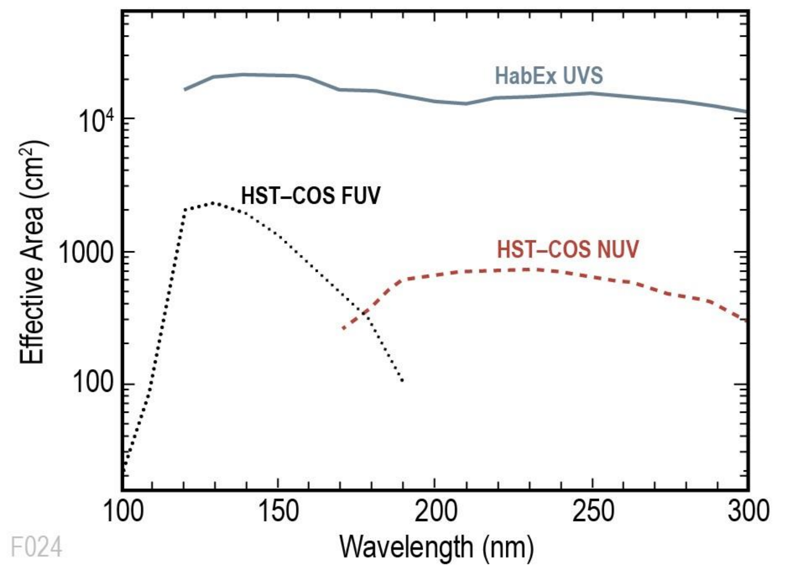


Capabilities: Resolution and Effective Area

Capabilities: Imaging and Spectra

- Diffraction limited at 0.4 μm
  - Better than all current or planned facilities for λ < 0.7 μm
- Non-sidereal tracking.
- Wavelength coverage
  - 115nm-1.8 μm
- Effective Area
  - >10x better than HST for 115nm-300nm
- UVS
  - Area 3’ x 3’, 115-300nm, resolution up to R=60,000
- HWC
  - Area 3’ x 3’
  - 150-400nm, 400-950nm, 950-1.8nm
  - R=2000



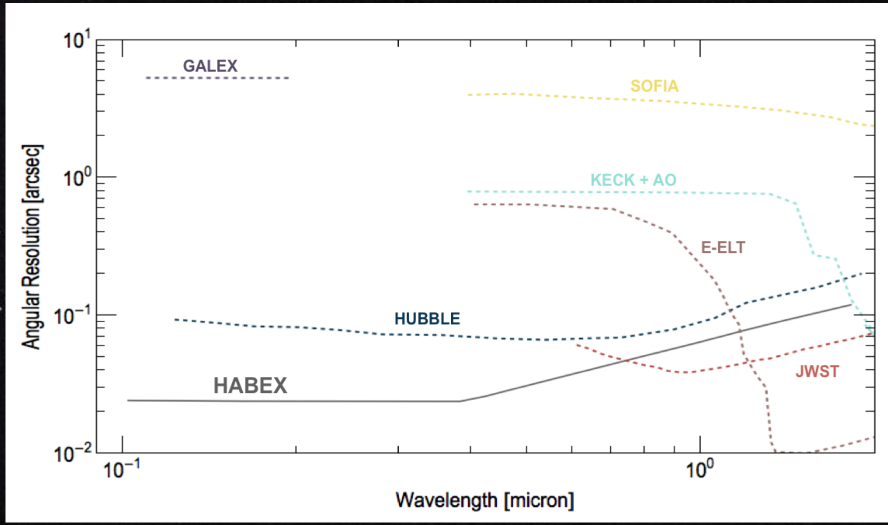


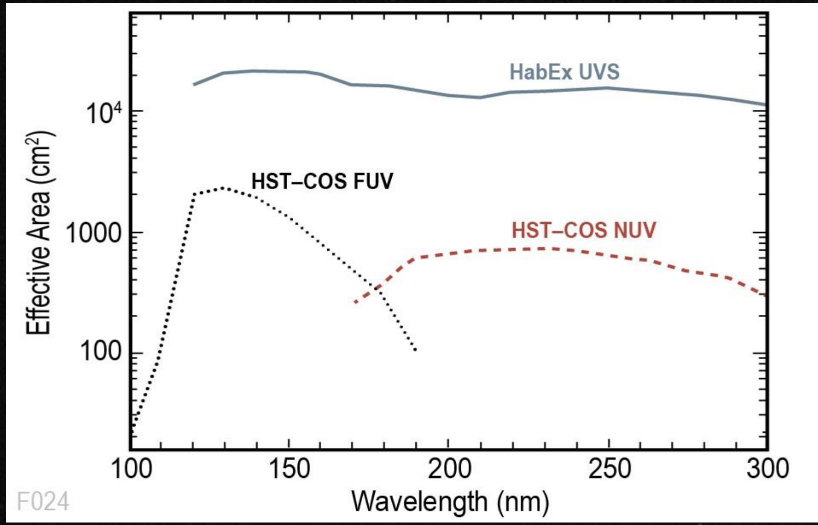
General Astrophysics and Solar System Science Themes

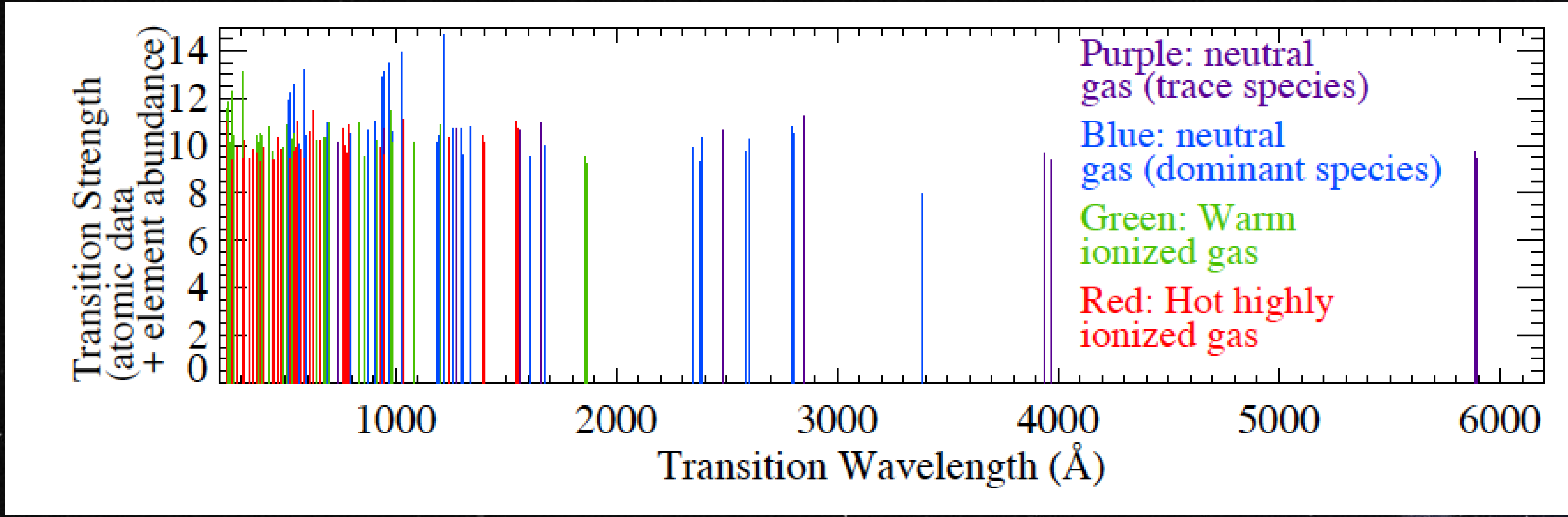
- The Life Cycle of Baryons and the Missing Baryons Problem
- Resolved Stellar Populations of Nearby Galaxies.
- Planetary Aurorae and Exospheres
- Cryovolcanism and Potentially Habitable Icy Worlds
- The Hubble Constant
- The Nature of Dark Matter Using Dwarf Galaxies

The Four Graces: John Clarke, Paul Scowen, Rachel Somerville, Dan Stern

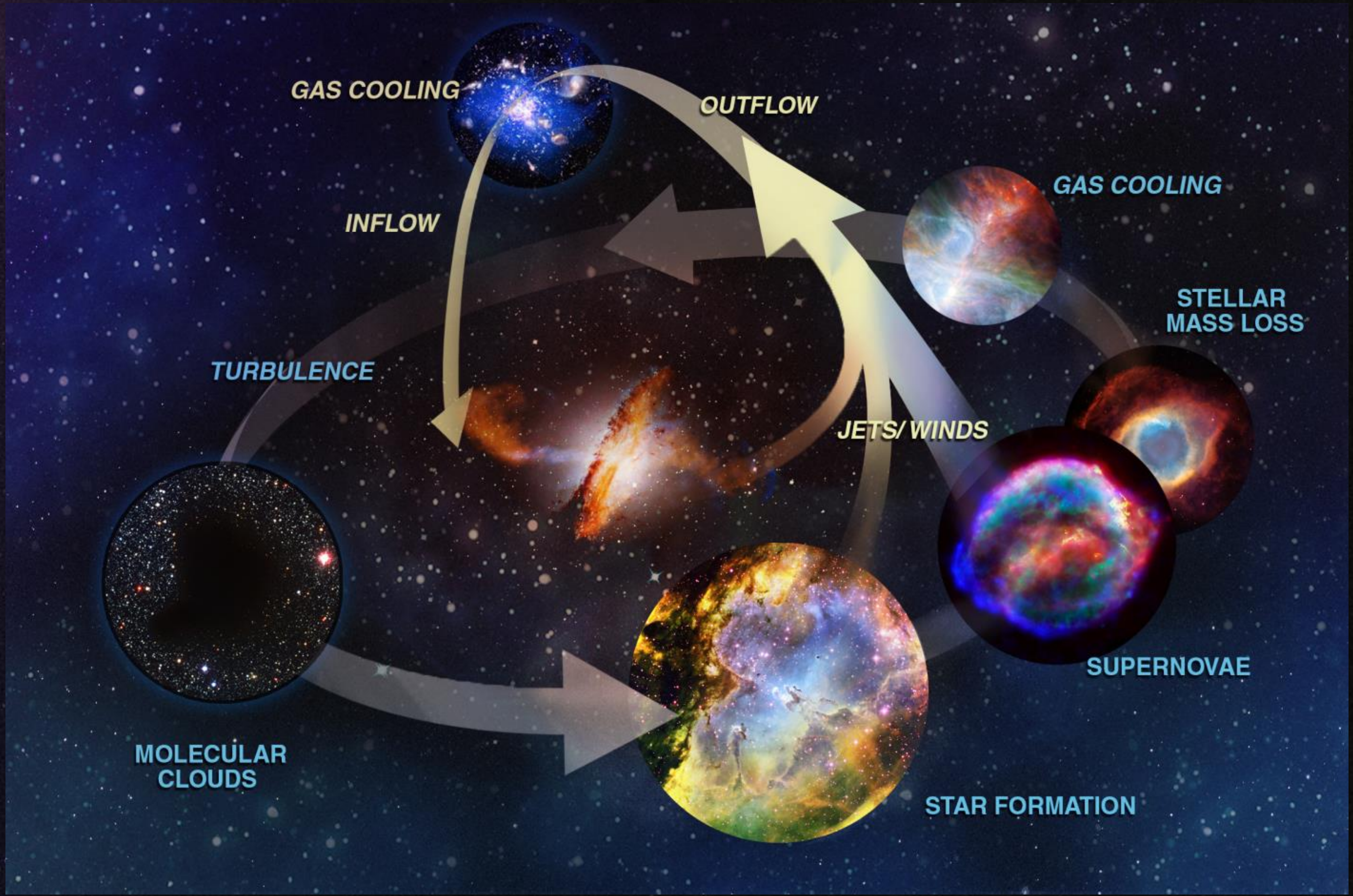
General Observatory Science

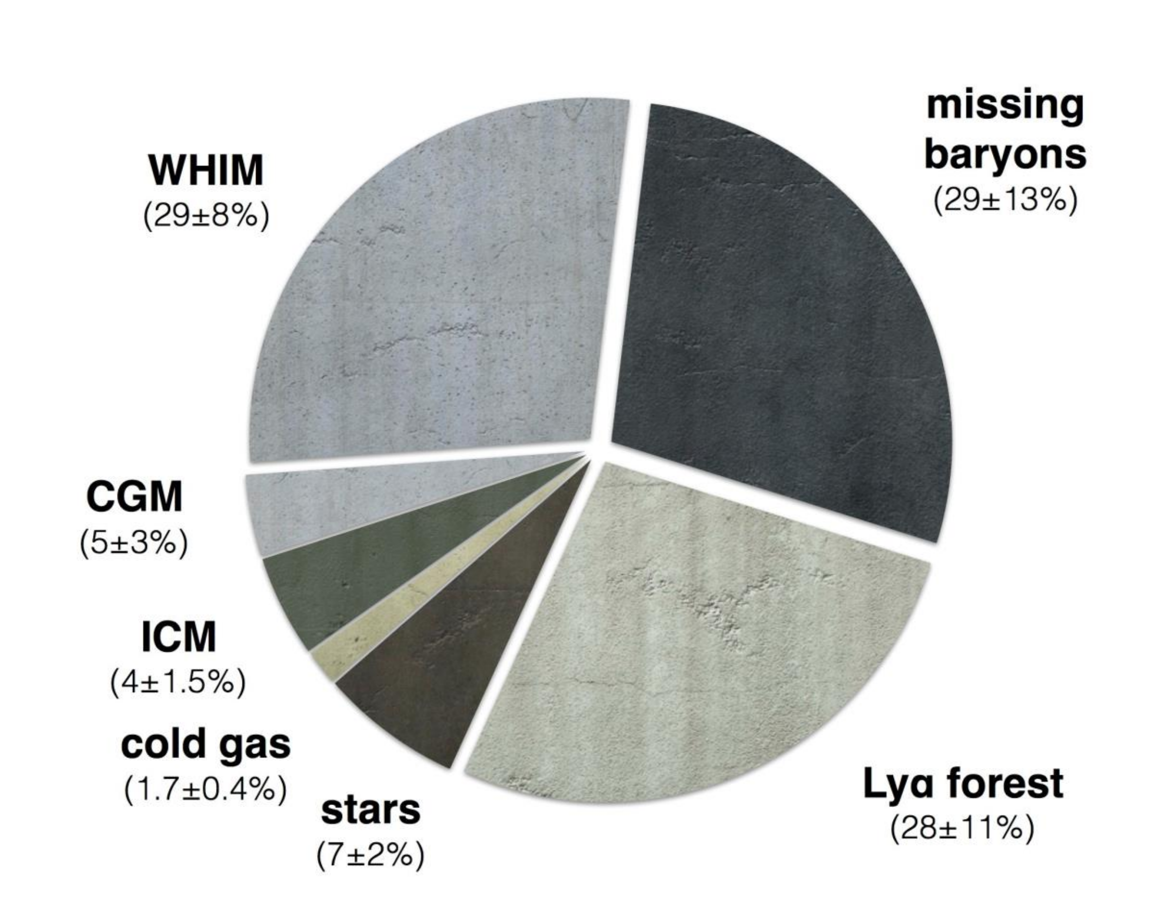




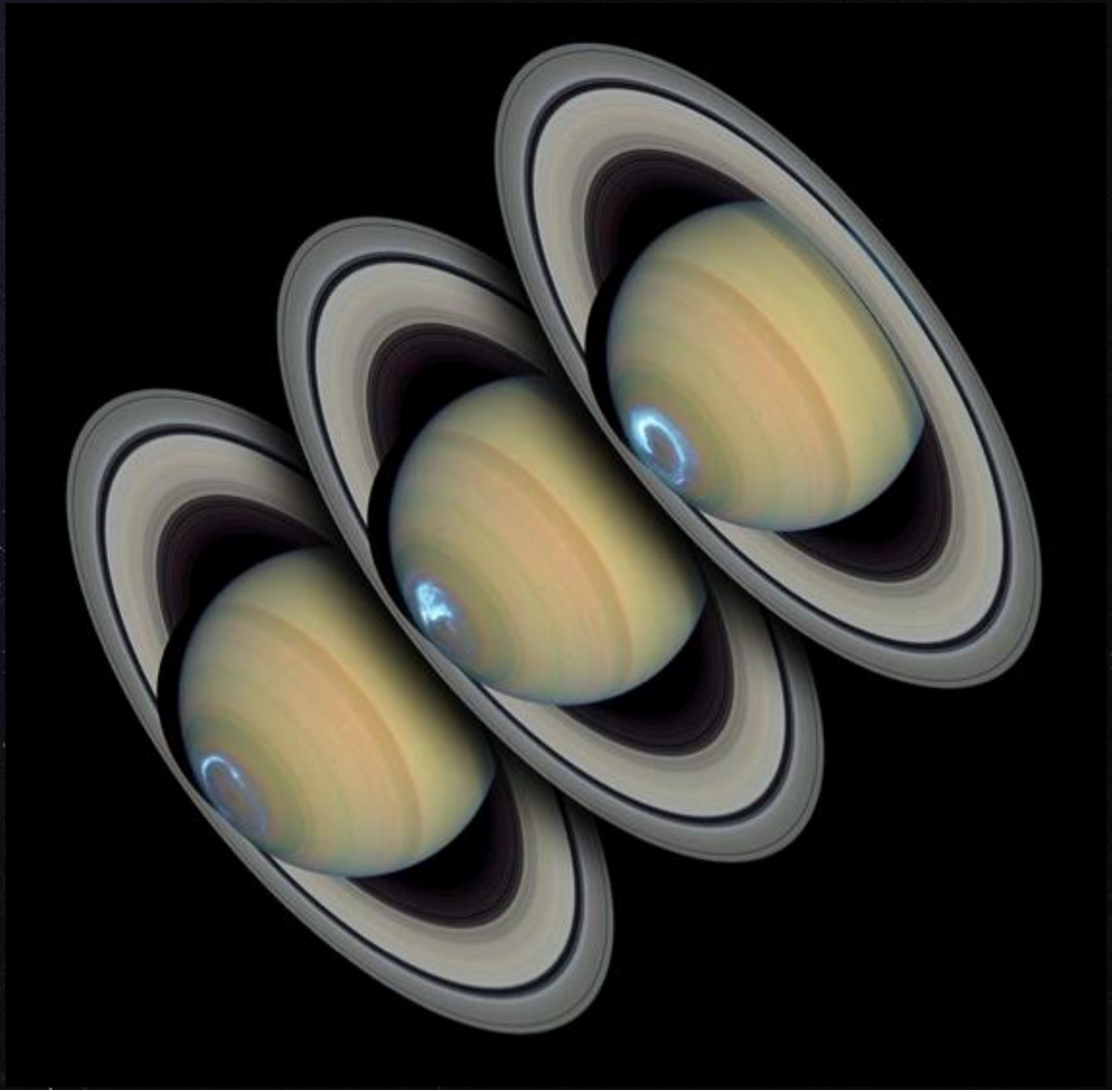


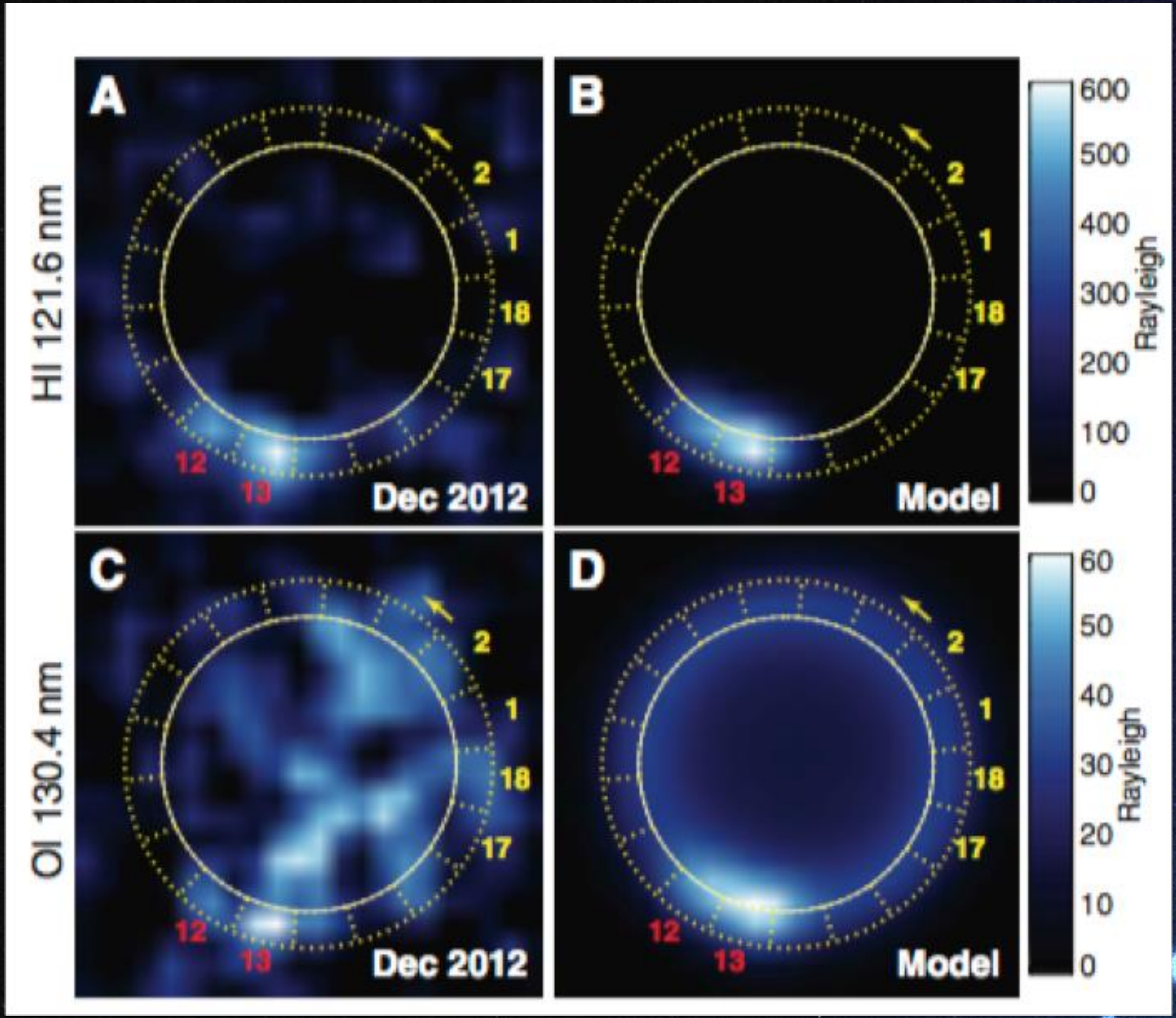
The Lifecycle of Baryons





Solar System Science





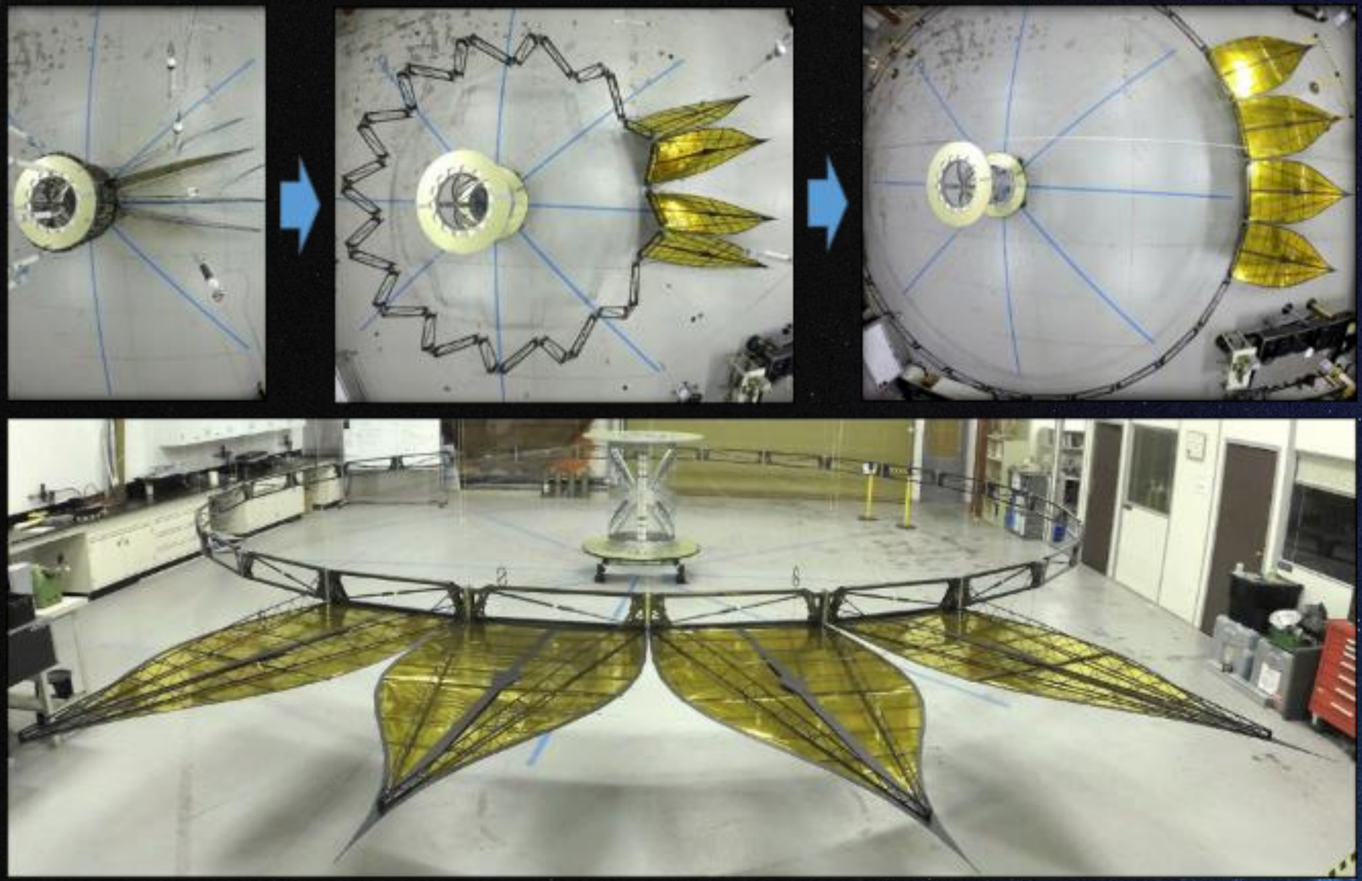
HabEx Technologies

	Starshade	Coronagraph	Technology Gap	ExEP TRL Assessment at P&L	Our Assessment at Final Report	
Enabling	■		Petal Shape stability	3	3	**High priority. Needs a plan.**
	■		Petal Position Accuracy	3	3	**High priority. Needs a plan.**
		■	LOWFS and control	3	4	**High Priority. Once we can demonstrate that we need only the same LOWFS implementation as WFIRST we can move to TRL 4.**
	■		Starshade Starlight Suppression	3	4	Technology being advanced in the S5 project
	■		Starshade Edge Scattering	3	4	Technology being advanced in the S5 project
		■	Micro-Thrusters	3	5	ExEP needed analysis that demonstrated that the existing thrusters would work for HabEx. We are doing this now. Once complete, the technology moves to TRL 5 since already demonstrated in space.
		■	Coating Uniformity on Large Optics	4	4	**High priority. Needs a plan.**
		■	Coronagraph Architecture	4	4	
	■	■	Large Aperture Primary	4	4	
	■		Formation Flying	4	5	Technology being advanced in the S5 project.
		■	Deformable Mirrors	5	5	
	■	■	Visible Detectors	5	5	
Enhancing	■	■	NIR Detectors	3	4 or 5	ExEP needs analysis showing that the current SOA will meet HabEx needs. May be able to leverage work in JWST to show HgCdTe detectors are suitable for the HabEx environment.

Technologies

Enabling technologies currently at TRL 3 for the 4m architecture to be matured.

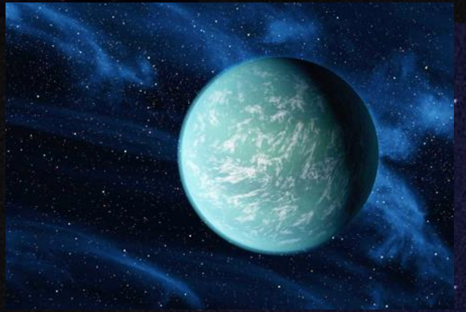
- Expected to be TRL >= 4 by Final Report
  - LOWFS and control
  - Starshade starlight suppression
  - Starlight age suppression and edge scattering
  - Microthrusters
- Needs investment to reach TRL >=4 by Final Report
  - Petal shape stability and shape accuracy



Summary

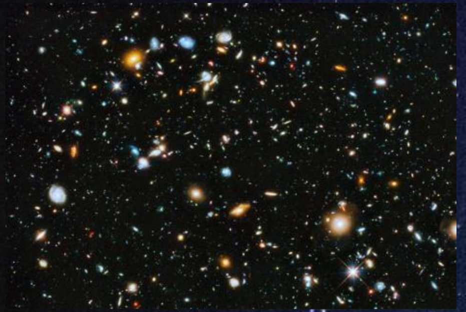
Architecture studied:

- 4m off-axis monolith: preliminary design completed.
  - Four instruments:
    - Coronagraph and Starshade Cameras
    - UV spectrograph and Workhorse Camera.



Science Goals:

- Seek out nearby worlds and explore their habitability
- Map out nearby planetary systems and understand their diversity.
- Open up new widows in the Universe from the UV to NIR.



Next Steps:

- Refine our observing strategy
- Create a full Design Reference Mission
- Decide on near-IR capabilities

Title	Presenter	Date • Time
HabEx Ultraviolet spectrograph design and DRM	Paul A. Scowen	10 June 2018 • 10:00 - 10:20 AM
The habitable exoplanet imaging mission (HabEx): science goals and projected capabilities	Scott B. Gaudi	11 June 2018 • 10:30 - 10:55 AM
Solid state detectors for the Habitable Exoplanet imaging mission (HabEx) and the large UV/optical/infrared (LUVOIR) surveyor mission concepts	Shouleh Nikzad	10 June 2018 • 11:10 - 11:30 AM
The habitable exoplanet imaging mission (HabEx)	Bertrand Mennesson	11 June 2018 • 1:20 - 1:40 PM
Overview of the 4m baseline architecture concept of the habitable exoplanet imaging mission (HabEx) study	Gary M. Kuan	11 June 2018 • 1:40 - 2:00 PM
The HabEx workhorse camera	Paul A. Scowen	11 June 2018 • 2:00 - 2:20 PM
Technology maturity for the habitable-zone exoplanet imaging mission (HabEx) concept	Rhonda M. Morgan	11 June 2018 • 2:20 - 2:40 PM
HabEx Space telescope exoplanet instruments	Stefan R. Martin	11 June 2018 • 2:40 - 3:00 PM
HabEx: high precision pointing architecture using micro-thrusters and fine steering mirror	Oscar S. Alvarez-Salazar	11 June 2018 • 3:30 - 3:50 PM
Numerically optimized coronagraph designs for the habitable exoplanet imaging mission (HabEx)	A J Eldorado Riggs	11 June 2018 • 3:50 - 4:10 PM
Overview and performance prediction of the baseline 4-meter telescope concept design for the habitable-zone exoplanet direct imaging mission	H. Philip Stahl	11 June 2018 • 4:10 - 4:30 PM
HabEx Lite: a starshade-only habitable exoplanet imager alternative	David Redding	11 June 2018 • 4:30 - 4:50 PM
Terrestrial exoplanet coronagraph image quality: study of polarization aberrations in Habex and LUVOIR update	James Breckinridge, Russell A. Chipman	13 June 2018 • 10:30 - 10:50 AM

Poster Title	Presenter	Date • Time
HabEx polarization ray trace and aberration analysis	**Jeffrey Davis**	**11 June 2018 • 5:30 - 7:00 PM**
HabEx space telescope optical system overview	**Stefan R. Martin**	**11 June 2018 • 5:30 - 7:00 PM**
HabEx telescope WFE stability specification derived from coronagraph starlight leakage	**Bijan Nemati**	**11 June 2018 • 5:30 - 7:00 PM**
Mirror design study for a segmented HabEx system	**James T. Mooney**	**11 June 2018 • 5:30 - 7:00 PM**
Overview and performance prediction fo the alternative 6.5-meter telescope concept design for the habitable-zone exoplanet direct imaging mission	**H. Philip Stahl**	**11 June 2018 • 5:30 - 7:00 PM**

Back-up Slides